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The Impact of Wearing Ballistic Helmets on Sound Localization

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Auditory localization performance was measured for test subjects wearing each of 4 ballistic helmets pre-selected by the United States Army. Data were collected at the Air Force Research Laboratory's (AFRL) Auditory Localization Facility (ALF) at Wright-Patterson Air Force Base (WPAFB). Localization response measurements were collected for subjects wearing the TC2001, MICH LW Fast, Sentry, and MICH helmet to understand the effect helmets may have on the user's ability to localize sounds. Results indicate that helmets that occluded even a portion of the ear degraded the user's ability to localize sound, to a greater extent than those for which the ear remained unoccluded, as determined by overall angular error, percentage of errors $> 45^\circ$, and front-back confusions. Localization performance was best when the subjects were wearing the TC2001 helmet, followed by the MICH LW Fast, Sentry, and finally the MICH helmet.

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EXECUTIVE SUMMARY

Auditory localization performance was measured for test subjects wearing each of 4 ballistic helmets pre-selected by the United States (US) Army. Data were collected at the Air Force Research Laboratory's (AFRL) Auditory Localization Facility (ALF) at Wright-Patterson Air Force Base (WPAFB) in March 2012. Localization response measurements were collected for subjects wearing the TC2001, MICH LW Fast, Sentry, and MICH helmets to understand the effect helmets may have on the user's ability to localize sounds. Results indicate that helmets that occlude even a portion of the ear degraded the user's ability to localize sound to a greater extent than those for which the ear remained unoccluded, as determined by overall angular error, percentage of errors > 45°, and front-back confusions. Results from the localization performance measurements were best when the subjects were wearing the TC2001 helmet, followed by the MICH LW Fast, Sentry, and finally the MICH helmet.

1.0 INTRODUCTION

Helmets are typically worn as personal protective equipment by military personnel for protection from ballistic impacts to the head. Ballistic helmets vary in size, shape, material, and comfort. One distinguishing characteristic between helmets is the degree to which the helmet occludes the ear of a user. Occluding the ear could degrade the user's ability to localize sounds by distorting the acoustic cues used by a listener to determine the location of the sounds. The objective of this study was to measure the impact of 4 ballistic helmets on auditory localization. The data were used to rank the helmets in terms of effect on a user's localization performance.

2.0 METHODS

2.1 Subjects

Localization response measurements were collected for subjects wearing the TC2001, MICH LW Fast, Sentry, and MICH helmets. Eight paid volunteer subjects participated in the measurements; 4 male and 4 female subjects ranging from 19 to 29 years of age. All subjects had bilateral hearing threshold levels less than or equal to 15 dB from 125 to 8000 Hz and had a minimum of ten hours of experience localizing sounds in the ALF facility.

2.2 Helmets, Sizing, and Fitting

The TC2001, MICH LW Fast, Sentry, and MICH helmets (Figure 1) were selected by the US Army for this study. The TC2001 and the MICH LW Fast helmets were designed with a high arch over the ear of the user. Regardless of user's head shape and size, these helmets did not occlude the ear. The Sentry and MICH helmets were designed to provide more physical protection on the side of the head, therefore occluding a portion, if not all, of the user's ears.

a. b. c. d.

Figure 1. Ballistic Helmets: a. TC2001, b. MICH LW Fast, c. Sentry, d. MICH

The sizing guide for each helmet specified head circumference as the only metric for fitting the shell of the helmets. Head circumference was measured from the front of the head, just above the eyebrows, above the ears, and around the back of the cranium. An additional measurement from under the chin to the crown of the head was taken and was used to determine the chin strap size. This measurement was not factored into the fitting of the actual shell of the helmet. As a result, subjects with narrow, oval shaped heads had less occlusion of the ears when wearing the Sentry and MICH helmets. Subjects with wider, rounded heads had a larger portion of the ear occluded when wearing the Sentry and MICH helmets. The high arch design of the TC2001 and MICH LW Fast ensured that the subjects' pinna were never occluded.

All subjects were initially fit with a helmet by a US Army representative with the use of the sizing chart from the operator's manual provided by each manufacturer. Head circumference was measured on each subject and is listed in Table 1 with the respective helmet sizes. If a subject's head circumference was between sizes, (s)he was, in most cases, graduated to the next largest size.

Table 1. Head circumference and helmet sizes per subject for each helmet type

Subject ID	Head Circumference (cm)	Helmet Size			
		TC2001	MICH LW Fast	Sentry	MICH
1	58	Large	Medium/Large	Large	Large
2	56	Medium	Small/Medium	Medium	Medium
3	55.5	Medium	Small/Medium	Medium	Medium
4	57	Medium	Medium/Large	Large	Medium
5	59	Large	Medium/Large	X-Large	Large
6	56.2	Medium	Small/Medium	Medium	Large
7	56	Medium	Small/Medium	Medium	Medium
8	57	Medium	Medium/Large	Large	Medium

2.3 Facility

All measurements were collected in ALF (Figure 2) at WPAFB in March of 2012. The aluminum-frame geodesic sphere is 4.3 meters in diameter with 4.5 inch loudspeakers equipped with 4 LED's located at each of the 277 vertices on its inside surface. The ALF apparatus is housed within an anechoic chamber. The subject stood on a platform in the center of this sphere. The platform was adjustable in order to center the subject's head in the center of the sphere. The location of the platform has the potential to distort the signals from the speakers located directly below the subject, therefore only 237 loudspeakers, evenly distributed, above -45° elevation, were used in this study. The distance between speakers ranged roughly between 8° and 15°.

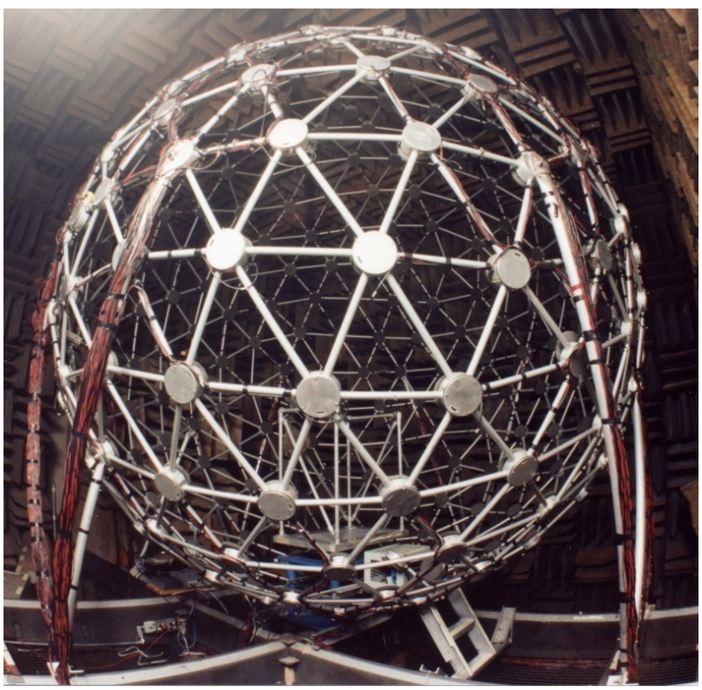

Figure 2. Auditory Localization Facility (ALF) at WPAFB

Subjects registered their responses with an Intersense IS-900 tracking system (Figure 3). The IS-900 used inertial-ultrasonic hybrid tracking technology to provide precise position and orientation information. The tracking system included a head tracker coupled with a response wand. The head tracker was mounted on the subjects' head to provide tracking data on the X, Y, and Z coordinate location of the head, as well as the yaw, pitch and roll during the duration of each trial. The response wand was equipped with a joystick and five buttons which could be programmed for various purposes depending on the task. For this study, the subjects were required to press a single button while pointing the wand at their desired response location.

Figure 3. Subject in ALF using Intersense IS-900 tracking system

2.4 Stimuli

The stimuli were presented to the subjects with two different conditions. In one condition, the stimulus was a 250-ms burst of broadband (200 Hz - 16 kHz) pink noise. This duration was chosen in order to reduce the possibility that a subject would initiate a head movement during the stimulus presentation. Such a movement would provide dynamic localization cues, which would result in improved performance. In addition many real world sounds encountered by the user are likely to be short duration (e.g. weapons fire, explosions). In another condition, a broadband (200 Hz - 16 kHz) pink noise was presented continuously until a localization response was made. This allowed subjects to make use of dynamic localization cues and move their heads during stimulus presentation to orient to the sound.

2.5 Experimental Procedures

The subjects were randomly assigned to conditions in order to eliminate any order effects. The test conditions were the 4 ballistic helmets and a control condition labeled as "No Helmet" meaning the subject would run the task without a helmet. The experiments in ALF were coded and executed using the MATLAB programming language by Mathworks™.

In each condition the experimenter fit the subject with the appropriate helmet. In each case, the rim of the helmet was placed a width of two fingers above the brow. The chin straps and nape strap were tightened snuggly to minimize any movement of the helmet on the head (Figure 1). The experimenter then directed the subject from the control room, where the fitting took place, into ALF. Once inside the sphere, the standing subject was raised or lowered by adjusting the height of the platform to ensure the subject's head was in the center of the sphere.

To start each trial the subject aligned his/her head to a loudspeaker located directly in front of them (0° azimuth, 0° elevation) and pressed a button on the response wand. A stimulus was presented randomly from one of the 237 speakers in the sphere. The stimulus was either a 250 ms burst of pink noise or a presentation of continuous pink noise. The subject would then locate and select the target speaker by pointing at it with the wand and clicking the response button to enter his/her selection. The LEDs on the speakers were activated when the subject pointed the wand at them. After a response was recorded, the LEDs of the target speaker was activated to give the subject feedback on his/her performance.

Each of the eight subjects completed 320 trials in the burst noise condition and 40 trials under the continuous noise condition for each of the four helmets and one control condition in which no helmet was worn. The ratio was weighted 8:1 for burst to continuous because the short bursts more accurately represented sounds a user would encounter in a real world environment. Both burst and continuous stimuli could be presented in a single block of trials. All stimuli were presented at 65dB.

3.0 RESULTS

Three metrics of particular interest were overall angular error, percentage of angular errors > 45˚, and percentage of front-back confusions. Angular error is the difference between the actual target location and the subject's response location as measured by the distance between the two points along the surface of the sphere. Mean angular errors in localization are shown in Table 2 and Figure 4 for each helmet condition in both the burst and continuous noise conditions. The mean overall angular error was similar when comparing the subjects' No Helmet condition response to the response when the subjects were wearing the TC2001 and the MICH LW Fast for both the burst and continuous noise conditions. When the subjects wore the Sentry and MICH helmets, the errors were greater for both the burst and continuous noise conditions relative to the errors in the No Helmet condition.

Table 2. Average overall angular error in degrees

	Overall Angular Error in Degrees	
	Burst	**Continuous**
No Helmet	11.46	4.07
TC2001	10.9	4.04
MICH LW Fast	11.82	4.63
Sentry	16.91	7.79
MICH	21.21	8.49

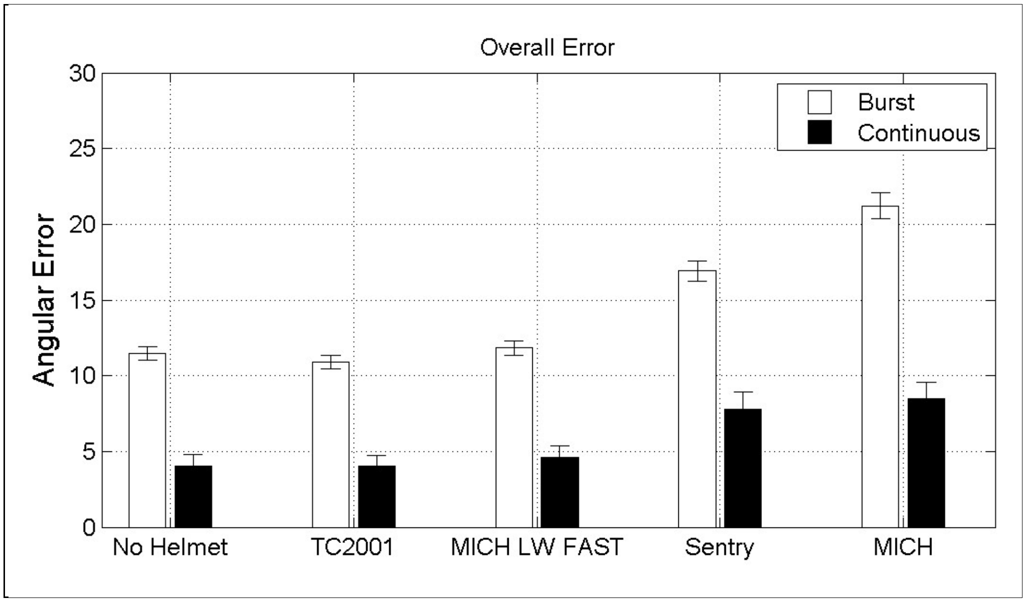

Figure 4. Overall angular localization error in degrees for burst and continuous noise conditions.

Table 3 and Figure 5 show the percentage of mean angular errors that were greater than 45˚ in each helmet condition for burst and continuous noise. The rationale behind including this measurement was its operational relevance. In general, we assume that if an operator's attention can be directed to within 45°, (s)he will then be able to use other sensory information, namely vision, to acquire the target. In the burst noise condition, the percentage of errors greater than 45˚ was negligible for the TC2001 and the MICH LW Fast (less than 2%). However, the percentage of errors greater than 45˚ for the Sentry and MICH helmets were 5% and 10%, respectively. In the continuous noise condition, the percentage of errors greater than 45˚ was negligible (less than 1%) across all helmets.

Table 3. Average overall angular localization errors greater than 45˚ in percent

	Overall Angular Error (> 45˚) in %	
	Burst	**Continuous**
No Helmet	1.48	0
TC2001	0.95	0
MICH LW Fast	1.6	0
Sentry	5.12	0.31
MICH	10.12	0.62

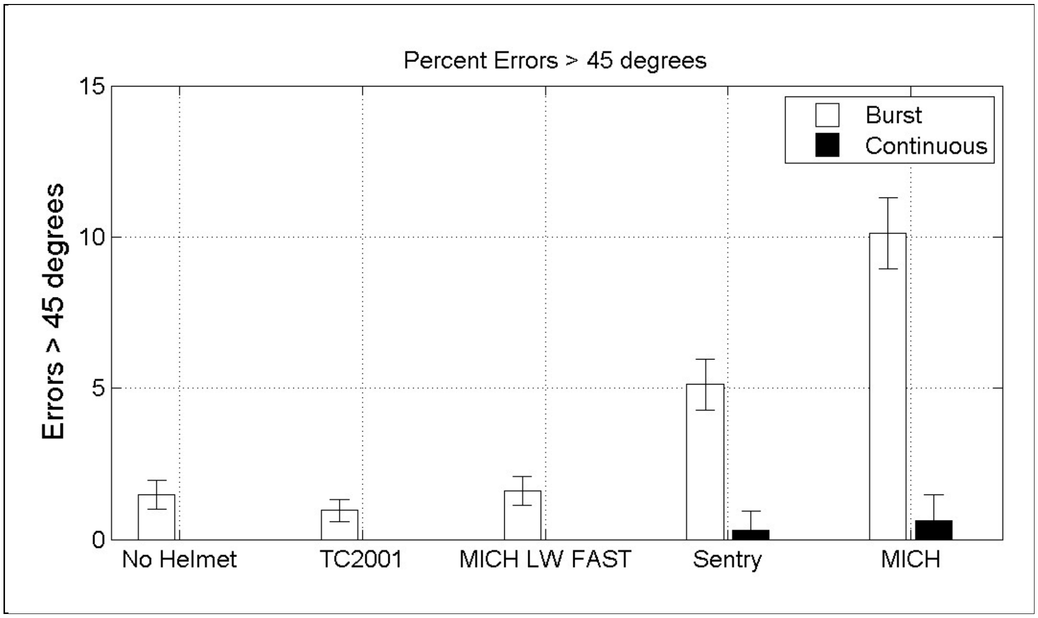

Figure 5. Percentage of overall angular errors > 45˚ for burst and continuous noise conditions.

Front-back confusions occur when a subject is unable to determine whether a sound is in front of them or behind them. The percentage of front-back confusions is displayed in Table 4 and Figure 6. The percentage of front-back confusions across all helmets for the continuous noise condition was less than 3% relative to the No Helmet condition. For 3 of the 4 helmets the percentage of front-back confusions was less than 1%. The helmets tested here appear to have no significant impact on percentage of errors subjects make due to front-back confusions.

Table 4. Average front-back confusion in percent

	Front-back confusion in %	
	Burst	**Continuous**
No Helmet	10.34	3.45
TC2001	10.79	2.68
MICH LW Fast	11.09	2.81
Sentry	11.1	1.87
MICH	12.93	1.87

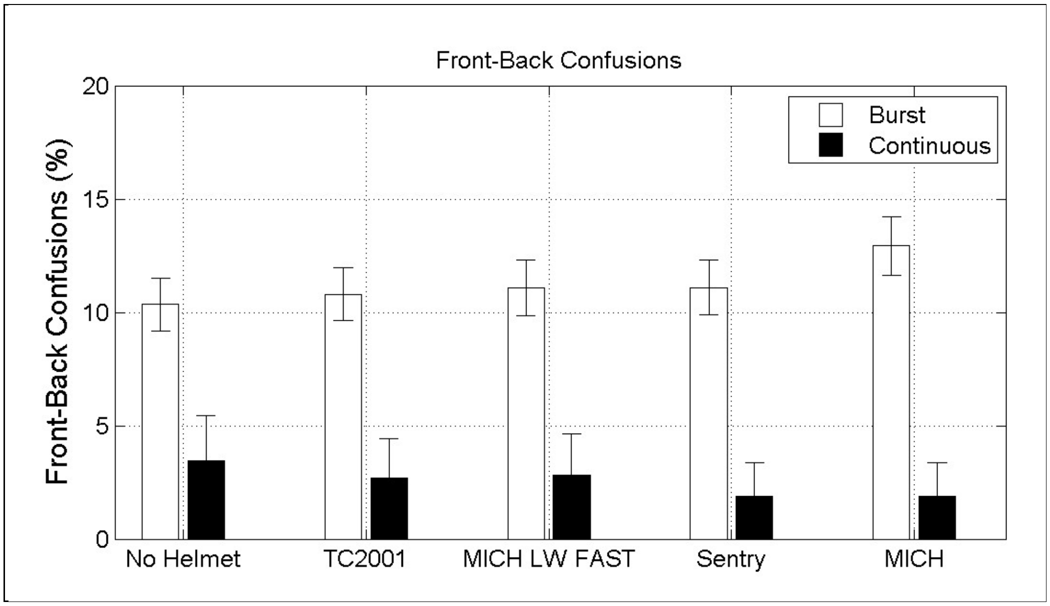

Figure 6. Percentage of front-back confusions for the burst and continuous noise conditions.

To directly compare the effect a ballistic helmet may have on the user's ability to localize sounds, the results of two measurements (overall angular error and angular error greater than 45˚) were rank ordered for both burst and continuous noise conditions. (Note: The percentage of front-back confusions was not used in this ranking due to the negligible impact all four ballistic helmets had on localization when compared to the No Helmet condition.) The order was selected based on the comparison of responses to the No Helmet condition. The two measurements were regarded as equally important so no weighting was used. The helmet yielding performance most similar to the No Helmet condition received a score of 1 while the helmet with the greatest difference received a 4. Table 5 shows the rank order for each helmet, each measurement, and a combined total for overall effect.

Table 5. Rank order - effect of localization performance while wearing ballistic helmet

	Angular Error		**Error (>45˚)**		**Total**
	Burst	**Continuous**	**Burst**	**Continuous**	
TC2001	1	1	1	1	**4**
MICH LW Fast	2	2	2	1	**7**
Sentry	3	3	3	2	**11**
MICH	4	4	4	3	**15**

4.0 DISCUSSION

Ballistic helmets were designed to protect the head of the user. However, if the helmet is occluding even a portion of the user's ears, the user's sound localization abilities are degraded. This degradation occurs because the helmet interferes with how sound travels to the ear and around the head. The 4 ballistic helmets that were assessed in this study fell into two categories: helmets that didn't occlude the ear (TC2001 and MICH LW Fast), and helmets that did occlude the ear (Sentry and MICH). Donning the TC2001 and MICH LW Fast had no significant impact on a subject's ability to localize sounds based on overall angular error, angular error greater than 45°, and front-back confusions. Donning the Sentry and MICH helmets did display some negative effect on the user's ability to localize sounds based on the same parameters. However, a trade-off may be necessary to fully protect the head of the user despite the evidence that the material of the Sentry and MICH helmets occluding the user's ears degrades localization.

The degradation of localization performance while donning the Sentry and the MICH helmets may have also been a result of how the helmet sits on the user's head. A user with a narrow, oval shaped head will have less occlusion from the Sentry and the MICH helmets due to the resting position on his/her head. A user with a wider, rounder head will have more occlusion of the ear due to the resting position on his/her head. The MICH helmet completely occluded the ear of one subject. Additional helmet sizes could help ensure a more consistent fit across users.

The application of these ballistic helmets must also be considered. If a user wears one of these ballistic helmets alone, the results of this study would prove valid. However, if the user adds any type of hearing protection device or communication device, his/her ability to localize could be negatively impacted. These helmets were designed to be worn with tactical headsets. Passive hearing protection devices, and more recently, in-the-ear tactical headsets, are also commonly worn in combination with these helmets. All of these devices could negatively impact localization performance and this should be a consideration in the selection criteria.

5.0 CONCLUSIONS

Ballistic helmets are worn as personal protective equipment. However, a partial occlusion of the ear due to the design of the helmet could have negative effects on the user's ability to localize sound and therefore could result in a degradation of situational awareness. Overall angular error, angular error greater than 45˚, and front-back confusion measurements were collected to determine if any negative effect on a user's localization performance was present when a ballistic helmet was worn. Overall, the helmets did have a negative effect on the subjects' localization performance. The helmets were rank ordered by comparing the results of the localization performance measurements with and without the ballistic helmets. As stated earlier, the helmets selected for this study fell into two categories: helmets that occluded a portion, if not all, of the ear (Sentry and MICH) and helmets that did not occlude the ear (TC2001 and

MICH LW Fast). The helmets that did not occlude the ear interfered the least with the user’s ability to localize sounds when compared to the helmets that did occlude the ear.